Recording Techniques for Digital Coded Data

ARTHUR W. TYLER

The communication links between the working interior of a digital computer and the external devices or persons that supply and make use of the data have long been recognized to be inadequate. It is also becoming apparent that this input-output equipment will be one of the major areas of cost in the great majority of computer installations, particularly in the nonscientific field. An intensive development effort aimed at producing satisfactory input-output devices is necessary, and a survey of the techniques which might be used should materially assist this program.

Two kinds of output equipment are required, one to produce coded records and the other to produce printed-type records. The comments to follow are directed primarily at digital coded recording.

A coded recording is used primarily as a means of transferring data from one device to another and to store data for future use. Data storage within a computer will not be considered as a recording process. The techniques overlap to some extent but the distinction will be made in terms of the amount of data that can be recorded. Specifically, a data recorder as distinguished from an internal storage unit is characterized by its indefinite capacity, its ability to record data as long as it is supplied with a recording medium.

The great variety of data-handling devices that will be used in the future will certainly involve the use of several different recording methods. In some cases it will be necessary to transcribe the data from one recorded form to another, to handle large quantities of data, and to record at very high rates. In the aggregate there will be so much coded data recorded that the storage elements will have to be very inexpensive. Chiefly because of this requirement, all of the recording techniques will have one outstanding common feature. The storage elements will have to be supported in some geometrical pattern on a suitable medium which permits selection to be accomplished by a mechanical movement of that medium. Accessibility will have to be sacrificed in favor of simplicity and low cost. The support usually takes the form of a long flexible tape which is moved past a device that records the data serially.

Although many of the materials that can be used as a recording medium are capable of recording signals of variable magnitude, reliability and simplicity dictate the use of a fundamentally binary code in which only the presence or absence of a signal is of significance. The binary digits are often grouped to form codes of more complicated structure, but no existing digital recorders use the signal magnitude as an additional dimension to increase the storage capacity.

An examination of the flow of data from one device to another reveals that there are three phases to be considered: the recording technique, the mechanical recording medium, and the playback technique. The data are assumed to originate in the form of electrical signals and eventually to be reproduced in the form of electric signals. The recording medium is the most critical phase of the process since limitations in the medium for the most part determine the success or failure of a recording method. All three phases must be considered as a combination in determining the merits of any specific material or technique because it is the combination which must be useful eventually. An ideal recording technique is useless unless there exists a satisfactory medium which will register and retain its output in a form that can be played back.

The characteristics of the medium which are of primary importance are:

1. Low cost.
2. Compactness. A high storage density is useful not only in reducing the volume of the material that must be handled and stored but also in reducing the velocity with which the medium must be moved to achieve a high recording and playback rate.
3. Permanency. It will be necessary to keep some records for many years.
4. Erasability. For some applications it is desirable to be able to erase and rerecord new data. For other applications it is equally desirable not to be able to change the record.
5. Durability. Some records will be played back a large number of times.

Desirable features to be sought in the recording and playback techniques are:

1. Simplicity and low cost. The equipment cost and maintenance charges will be the principal limitation to widespread use of this equipment.
2. Reliability. A high degree of reliability in reproducing the electric signals that were impressed on the recorder is of course desirable, and essential to some applications. However, it should be recognized that there are situations, such as the handling of statistical information, in which reliability can justifiably be sacrificed to attain other advantages.
3. Recording and playback rates. Here again a wide range of recording rate requirements will be encountered and the available recording techniques limited accordingly.

The application will dictate the requirements, and that recording technique and type of medium which has the best combination of features will be selected for the job.

The mechanical nature of the recording medium and of the process of selection by moving the medium imposes limitations on the extent to which the inherent characteristics of the medium can be utilized. These limitations are for the most part in the same order of magnitude for all of the practical forms of recording now in use. This important point is brought about by the fact that our level of technological development permits the attainment of positional accuracies of a few thousandths of an inch, velocities of a few feet per second, and accelerations to produce these velocities in a few milliseconds with the materials which we must use. The cost of exceeding these limits soon becomes prohibitive. The proper combination of properties is more important than perfection in any one in selecting a recording medium.

The Recording Techniques

A quick survey of the techniques that are now being used for recording digital data reveals that they fall in three categories: mechanical, magnetic, and optical. These terms also describe three of the five fields of classical physics, namely, mechanics, sound, heat, light, and electricity and magnetism. This observation suggests that it might be worth while to digress for a moment to survey each of these five fields for information relative to digital recording. Recording techniques differ primarily in the way in which the medium is altered during the
recording process. The survey should emphasize techniques for altering or modulating the medium using the forms of energy studied in each field.

Mechanical modulation can be accomplished by removing material as in perforating, adding material as in printing, or displacing material as in embossing. All of these methods have been tried in one form or other. The perforating technique has been most commonly used because it is the easiest way of recording but because of the convenience in playing back by mechanical means. The printing technique deserves much more attention than it has received and will be considered in more detail later. Embossing does not have any particular advantages.

In the field of sound there appears to be no useful technique for permanently modulating a mechanical medium. Sonic techniques are, of course, widely used for internal data storage but their application has been confined to that field.

From the field of heat there are available heat-sensitive papers which are used in facsimile recording. Modulation is accomplished by producing a chemical change in a suitable material by the application of heat. The technique could be applied to digital recording as well. In general, however, heat is the most difficult form of energy to control and is not likely to be very adaptable to this use.

There are many materials that can be altered under the influence of light. Photographic materials are the most widely used. Their success hinges on the use of a chemical means of amplifying the effect of the light. This procedure permits the achievement of extremely high optical efficiency in terms of the effect produced by a given amount of light energy. This high efficiency is reflected not only in the magnitude of the change but also in the time required to produce it. Photographic recordings have been made in time intervals less than 10^-8 second. The only other optically sensitive materials which have a satisfactory combination of properties for digital recording are the phoshors. Materials are available which can store energy from optical excitation and which will radiate that energy later under the influence of optical stimulation. The process is repeatable so the medium is erasable. It is quite likely that a satisfactory phosphor could be developed for digital recording with a reasonable amount of effort. There are many photochemical reactions which might conceivably be developed into a useful form.

However, the likelihood of attaining sufficient sensitivity is not very great.

The field of electricity and magnetism offers many ways of producing modulation on a mechanical medium. Most of these methods are reversible and have the further advantage that the recording element is relatively simple because the source of information is in the form of electric signals. Electrochemical reactions, the deposition of electrostatic surface charge, electrical displacement in a dielectric material, and the magnetic orientation of permanent magnetic materials are representative of the methods that have been tried. Magnetic orientation is the only method which has developed into a practical recording means. The electrostatic technique has been applied successfully to internal storage.

The principal techniques that are now being used for recording digital coded data make use of perforated paper tape, cards and magnetic tape or wire as the recording medium. Photographic film has been tried but its use has not become general. There are two other recording techniques which have sufficient merit to warrant further study for some applications, namely, printed paper tape and photographic plates. Each of these five techniques will be discussed in detail. Somewhat more time will be devoted to the discussion of photographic techniques than to the others, not because they are considered to be more applicable, but because it has been specifically requested in view of the relative lack of published information on that subject.

Perforated paper tape is one of the simplest and oldest means of recording coded digital information. The tape is mechanically perforated during recording and the perforations are sensed mechanically during playback. Multiple channels are almost always used to store one symbol as a pattern of bits arranged in a lateral line. Use of a recording density of about 100 bits per square inch is common practice. Teletype equipment employing this principle has been used successfully for many years. The principal limitations of perforated paper recording are the relatively low operating speeds and recording densities that are practical to attain. The recent introduction of photoelectric sensing has improved the speed and reliability of playback. The real limitation, however, is the low storage density since that in effect also imposes a speed limitation due to the limited velocity with which it is practical to move the tape. There is little likelihood that the perforating technique can be improved to overcome this limitation. Perforated paper tape will still be used, however, until the newer techniques are perfected.

Perforated paper cards have also been used very extensively for many years, particularly in the business machine field. Even though the storage density is only about 25 bits per square inch, there are so many other advantages arising from the discrete nature of the cards that they will certainly continue to play a prominent part in automatic computation. A good part of the flexibility and operating speed of punched-card equipment is attained by parallel operation in many channels. This feature increases the cost and maintenance of the equipment.

Magnetic recording is currently the most widely used recording method for those applications to which perforated tape or cards are unsuited. The flexibility of being able to erase and re-record selected portions of the record is the most important single reason for this trend. The principle involved in magnetic recording has been known for a long time and has been extensively applied to sound recording. Various kinds of magnetic materials are employed. The usual form consists of a thin coating of finely divided iron oxide on a plastic tape. Plated metal tapes and plated or solid wire are also used. A binary digit is recorded by magnetizing a small area of the tape using the fringing flux near a small air gap in a magnetic circuit. The material has sufficient residual magnetism after the tape has passed the recording gap to remember the impressed signal. Playback is accomplished by passing the tape across the air gap of a similar magnetic circuit. When a magnetized spot is encountered, a voltage is induced in the playback head. This voltage is the time derivative of the recorded signal and must be treated accordingly.

Magnetic wire has not been used extensively because only one recording channel is available and the wire is more difficult to handle. With magnetic tape several channels can be recorded simultaneously. This feature provides a convenient means of increasing the recording rate without having to increase the tape velocity. It is more practical to provide multiple electronic circuits for recording and playback than it is to drive the tape faster, a further reflection of the fact that the mechanical problems associated with recording are the more severe. The use of multiple channels is also advantageous in some cases because of the code structure that is used.

Tyler—Recording Techniques for Digital Coded Data
There are several variations in the way in which the magnetized areas are used to represent the ones and zeros of binary digits. Perhaps the most straightforward method consists of recording ones and zeros as magnetic spots of opposite polarity on a background of unmagnetized material. When this record is played back, a positive and a negative voltage pulse is generated for each bit regardless of its value, so no additional synchronization is required. The two digits differ in the order in which the two pulses occur. If a synchronizing channel is employed to sample the other channels at definite locations, other techniques can be used which permit closer spacing of the pulses.

It has been found practical to record between 100 and 200 bits per inch in each channel. The spacing of channels across the width of the tape is restricted somewhat by the physical structure of the recording heads. About 20 channels per inch have been attained with careful design resulting in an over-all storage density in the order of 2,500 bits per square inch. The usual practice in recording from a computer is to group the data in blocks of some convenient size and separation on the tape thereby facilitating control of the flow of data to and from the recorder. In the case of magnetic recording the block separation is essential if it is desired to stop and start the tape, since the tape must be moving faster than a prescribed minimum velocity during playback in order to induce sufficient voltage in the pickup coil.

A magnetic storage element is unique among the common recording materials in that the stored signal has direction as well as magnitude. It can be used as a ternary storage element having three useful states, positive, negative, and zero, without having to resort to amplitude discrimination. This feature could be used to increase the recording density through the use of a ternary number system but it is ordinarily used to record binary digits without having to use the absence of a signal to denote the digit zero. This feature effectively doubles the storage density since it would otherwise require two binary storage elements to achieve the equivalent result.

The important desirable features of magnetic tape recording can be summarized as follows:

1. Relatively high storage density resulting in a compact record.
2. A high recording and playback rate compatible with the requirements of electronic computers.
3. Good flexibility due to the ability to erase and rerecord and to play back without delay.
4. Provision for multiple channels.
5. A high degree of permanency.

Magnetic tape has some disadvantages which are of more or less importance in specific applications. Among these are:

1. Intimate contact between the tape and the reading and recording head is necessary to take full advantage of some of the desirable properties. Close contact is difficult to maintain and results in excessive wear.
2. It is difficult to manufacture magnetic tape without producing an appreciable number of blemishes which render a localized area unsatisfactory. This situation will undoubtedly be improved in the future.
3. Data cannot be played back unless the tape is moving in excess of a minimum velocity.
4. The erasability feature permits the possibility of accidental or even malicious erasure of a record that is desired to be permanent.
5. It is difficult at best to inspect the tape visually, to determine what has been recorded particularly as an aid in troubleshooting.

Magnetic recording for digital purposes is still a relatively new technique. Further development to increase the reliability and reduce the cost of the equipment will very likely produce recorders which will play an important part in the handling of information for many purposes.

The Photographic Process

The photographic process is probably the most versatile and certainly one of the widely used recording techniques available. In the nondigital field and particularly in the field of pictorial reproduction where a large amount of detail must be recorded, photography is unsurpassed by any other recording technique. It is rather surprising, in view of its many useful properties, that it has not been tried more extensively in the digital field. It is the writer's belief that the principal reason for this lack of interest has been the preoccupation on the part of computer designers with recording techniques that are erasable. Now that a relatively greater amount of effort is being directed at solving the input-output problem, designers will be searching for other recording techniques and the use of photography will undoubtedly be studied extensively.

One of the chief attractions of photographic materials is the relatively high resolution of which they are capable. It is not unusual for images to be composed of distinguishable elements in the order of 0.001 inch in diameter. It is not too unreasonable to assume that digital recording with 1,000 bits per linear inch might be practical. However, it should be emphasized again that the limitations in digital recording are mechanical. The problems of transporting a continuous strip of 16- or 35-millimeter film are substantially the same as those encountered with paper or magnetic tape. It becomes necessary to make the storage elements considerably larger than 0.001 inch in order to be able to locate them with adequate certainty during playback.

It is interesting to indulge in a little wishful thinking to see what might be done if the mechanical problems could be solved with sufficient precision. Photographic materials are available which can resolve at least 75,000 lines per inch, which represents the limit of our ability to measure the resolving power. It is already beyond the capabilities of optical instruments using visible light. The material must be exposed using an X-ray diffraction pattern and later examined in an electron microscope to observe the line structure. This photographic material could easily record over 5 billion bits per square inch with adequate definition.

The individual photographic storage element consists of a rectangular area containing a spot which is either transparent or opaque, to represent the two binary digits. Multiple-channel recording would almost always be used since it is one of the virtues of photographic recording. The use of a synchronizing channel to determine the position at which the other channels should be sampled is the most practical procedure. The spots can then occupy the full extent of the area allotted to them, thus providing the maximum tolerance for mechanical errors in positioning the film. The optical means of recording results in a channel spacing which is determined by mechanical positioning tolerances rather than by structural size limitations. A practical storage density is 100 spots per inch in the direction of film motion and 50 spots per inch laterally. The rectangular dimension is best for two reasons. There are a fewer number of disturbances contributing to the longitudinal positional error because of the mechanical scanning that takes place in that direction. Secondly, a dust particle or scratch is less likely to obliterate completely a rectangular spot than a square spot of equal area. The exact size and shape of the spots are not too critical. They can be somewhat smaller.
if precautions are taken to eliminate dust and prevent scratching. We have played back spots of this size using photovoltaic sensing several hundred million times without error.

The physical characteristics of the film support which carries the photographic emulsion are well suited to this use. These materials have been perfected over a period of many years for motion picture purposes. There is available a wealth of data and experience on the properties of film base and methods of transporting it from which a practical recorder design could easily be evolved. Film bases are subject to dimensional changes resulting from aging and varying atmospheric conditions. These effects have been thoroughly studied and are sufficiently small to be easily eliminated through proper design. The film support has excellent wearing qualities and can be mechanically guided to a tolerance of the order of 0.001 inch without much difficulty. It is quite practical to move the film support in sliding contact with a supporting structure provided the contact is outside of the recording area. Films handled in this way have a life expectancy of several thousand passes. However, an emulsion dust is formed under these conditions which tends to adhere to the film surface. This dust can be removed readily but it is preferable to handle the film entirely with rolling contact. This technique further increases the film life and materially reduces the collection of dust and scratches.

A wide variety of photographic emulsion types are available from which a selection can be made to meet the specific requirements of practically any recording problem. High-sensitivity emulsions can be selected to meet high recording rate requirements. High-contrast materials can be used to attain a large difference in optical transmission between the light and dark spots, effecting a high signal-to-noise ratio. Some materials can be reversed during processing to obtain clear spots in place of black spots, a feature which is particularly useful in some applications. The manufacturing techniques for photographic materials have been perfected to a point where very high quality can be maintained. The presence of a blemish that would obliterate one spot of the dimensions specified is extremely rare, certainly less than one in 100 million spots.

Both the recording and playback techniques used with photographic film will be based on optical methods. In many respects this is a considerable advantage, particularly since no physical contact with the recording medium is required. It is also possible to record and play back in several channels with a single modulation and detector. This is accomplished by handling the channels in time sequence using optical scanning. Actually it is a single-channel method of recording in which optical means are used to record in a 2-dimensional pattern rather than in a linear array as a single channel ordinarily implies. This procedure requires both the flexibility which optical scanning provides and the high sensitivity and frequency response which is available with photographic recording and photoelectric playback.

Light sources with sufficient brightness and modulation capabilities are available for recording a pattern of dots on a photographic medium. A cathode-ray tube meets these requirements, especially when high recording frequencies are desired. An opaque mask with a series of rectangular apertures of the desired shape is placed over the face of the cathode-ray tube. An image of this mask is projected onto the film by a suitable optical system. The cathode-ray tube beam is displaced in such a way that it illuminates selected apertures in sequence. There are many ways of combining the beam deflection and the arrangement of apertures to use the film area efficiently and to realize such features as the positive recording of both zeros and ones. One satisfactory arrangement has two lateral rows of apertures each of which records in alternate channels. This permits placing the channels immediately adjacent to one another on the film and at the same time forming the spots with clearly defined edges. This technique has been used to record data at the rate of 1,000-000 bits per second.

Glow lamps may also be used as a source of illumination for the apertures in the spot-forming mask. A separate glow lamp is used for each channel. The recording rate is limited by the brightness and modulation capabilities of the glow lamp to about 1,000 bits per second per channel.

When recording rates in the order of ten per second or slower are satisfactory individual incandescent lamps can be used as the source of illumination. Incandescent lamps with fine filaments and gas filling can be modulated up to about 20 cycles per second. Individual electromagnetic shutters and a common light source are also quite satisfactory.

A very convenient method of shaping the spots in a single line without spaces between spots involves the use of what is called an optical light pipe. A transparent glass or plastic rod can be bent into any reasonable shape, and light introduced at one end will emerge from the other end without much loss. A series of rectangular rods are arranged with their outlet ends forming a line of adjacent spots and their inlet ends at the light sources which are located in some other convenient geometrical arrangement.

A straightforward method of playback consists of illuminating the film with a steady light source and projecting an image of the film onto a row of photoelectric cells, one for each channel. The optical system is designed so that the image of each spot is projected onto an aperture which is smaller than the spot image to accommodate mechanical positioning errors. A synchronizing channel is used to generate a timing pulse when each row of spots is properly positioned in the optical system. The film can be moved either continuously or intermittently on a line-at-a-time basis. Lead-sulphide photoconductive cells are excellent detectors for this purpose. Multiple sensitive areas can be fabricated to any reasonable shape and size and can be grouped together on a single supporting surface. Lead-sulphide detectors are much more sensitive than vacuum phototubes for this application. Their frequency response, however, is limited to the order of 10,000 cycles per second.

A single photoelectric cell in conjunction with optical scanning can also be used for playback. A cathode-ray tube and mask, similar to that used for recording, serves as a light source and scanning system. Playback rates of 1,000,000 bits per second are attainable although there is some difficulty with the persistence of the phosphor at these frequencies.

The advantageous features of photographic film are:
1. A high storage density and the high recording rate which is thus made possible
2. A long wearing material
3. A high degree of permanency
4. Multiple channels and the applicability of optical scanning
5. Visibility of the record for inspection
6. There is another feature which is unattainable with any other recording medium and which is consequently a decided advantage for those applications that require it, namely, the ability to record a pictorial image along with the digital code. This image may consist of graphical data, a reduced image of a document, or any other information which is not conveniently expressible in digital form. This combination of microfilm recording and digital recording and control will embrace new fields which cannot be handled by either technique alone.

Tyler—Recording Techniques for Digital Coded Data
The disadvantages of using photographic film are principally the disadvantages of the photographic process in general. The materials must be handled in darkness, the images are nonerasable, and the material cost is relatively high. The principal disadvantage is the necessity of chemically processing the film before it can be played back. Techniques for processing the film have been greatly improved during the past few years and the development of automatic equipment is continuing. A processing machine no longer need be the cumbersome, time-consuming, and somewhat messy device that most people visualize. The disadvantages of processing can now be reduced to an acceptable level.

The principal drawback to the use of paper tape is the low storage density resulting in low recording rates. The use of optical sensing substantially eliminates playback limitations so, if there were available a recording technique capable of high recording rates and high storage density, this medium would find many applications. The mechanical printing technique used in the Eastman printer to be described by Mr. Thompson is adaptable to coded digital printing and will meet these requirements reasonably well. With very little change in design the electromagnetic hammers used in this printer could be grouped to print a pattern of dots of substantially the same size and spacing as that used with photographic film. Each hammer would print approximately 100 dots per inch in a separate channel. A total of about 20 channels could be accommodated with a spacing of about 1/50 of an inch per channel. A recording rate of about 2,000 bits per second per channel could easily be attained. There is no convenient way of erasing and rerecording but the material cost is so low that it would be practical to apply this recording technique to some applications which now require an erasable medium.

The advantages of this type of recording are high storage density, moderately high recording rates, visibility for inspection purposes, and low cost. Compared to other recording methods there are no serious disadvantages except possibly the necessity of using a carbon paper tape with the recording paper.

It has been pointed out that the storage density limitation of photographic materials is due to mechanical tolerances. It is possible to reduce the mechanical limitation materially by using an entirely different concept for the recorder design. Instead of using a long tape, the recording medium is fabricated as a rigid disk which is provided with a precision bearing. Accurate rotational motion is available without great complication. A suitable recording medium is a photographic glass plate. The dimensional stability of the glass plate is limited only by thermal expansion and is consequently considerably better than film base. It is estimated that a storage density of about 1,000,000 bits per square inch could be achieved with a photographic disk recorder. A disk 6 inches in diameter could store over 10 million bits which is equivalent to about 150 feet of 35-millimeter film or 750 feet of 10-channel magnetic tape. One practical design uses a bank of glow lamps to record in multiple channels which are spiral shaped. The lamp bank is displaced radially as the disk rotates. The rotational method of transporting the glass disk eliminates trouble arising from scratches and provides a very long life. It would be necessary to take precautions to eliminate dust interference. Disturbances of this nature will no doubt impose a lower limit on the spot size that can be used. This limit must be determined experimentally.

The advantages of this type of recorder are extremely high storage density, small physical size, low material cost per bit, and relatively quick access to all of the data. The disadvantages are substantially the same as those associated with photographic film. There is the danger of breakage but glass plates in the form of disks are not particularly hard to handle.

In conclusion, it should be emphasized again that the most difficult part of the design of a digital recorder is the mechanical transporting and locating of the recording medium. Considerable effort in solving that problem thoroughly is well justified. All of the practical recording techniques should be exploited since all of them will find application in the great variety of digital recording that will soon be required. Emphasis should be placed on the development of simple devices since the largest potential field consists of the many small applications rather than the few large installations.

---

Discussion

K. P. Gray (Royal Canadian Navy): How many bits of information did you say existed on the 6-inch-diameter disk?

Mr. Tyler: About 10,000,000 bits can be put on a 6-inch disk. This allows for some spacing, because of the fact that they are distributed in a circle rather than in a straight array. The actual spot size that can be achieved is 0.001 inch on a side.

J. J. McDonald (Consolidated Engineering Corporation): What has been done with color to increase recording density?

Mr. Tyler: The cost of most color processes would be prohibitive, I believe. We have used color for one specialized purpose, not so much to increase recording density, but to provide a means of matching two numbers. The use of color will allow you to tell when the numbers are mismatched and, also, which number is the larger. However, as far as using it to increase recording density, I know of nothing that has been done.

Harry Smith (Sperry Gyroscope Company): I am interested in knowing how you would extract information, that is, playback from printed data on paper.

Mr. Tyler: The same type of equipment would be used that is used to play back Teletype tape. You would have to read the information photoelectrically by reflection rather than by transmission. This procedure is somewhat more difficult, but quite practical.

M. J. ReUs (Control Instrument Company): What is the minimum time expected for a recording to play back with these photographic techniques, taking into account development time?

Mr. Tyler: That depends to a great extent on the application you have in mind. It is possible to process film and project an image from it in a fraction of a second. You could do that on a continuous basis. However, I see no reason for doing it for digital purposes. In a more conventional processing technique where the roll of film is removed from a recorder and then processed in a separate machine, a processing time of the order of a few minutes is possible.
Punched-Card to Magnetic-Tape Converter

E. BLUMENTHAL  F. LOPEZ

The principal devices for converting source data to magnetic tape recording for Univac* are the card-to-tape converter and the Unityper.* Unityper is the logical conversation medium for input of otherwise untreated data. Files of punched cards, however, represent to the owner an investment of time and expense in preparing material for other treatment. The card-to-tape converter provides a means whereby these files can be made immediately available for use in Univac.

The specifications for the Univac system card-to-tape converter shown in Figure 1 evolved from consideration of the characteristics of various punched-card systems already in existence, and of the specifications of the more recently designed Univac. The largest quantity of card-encoded data has been prepared on 12-row 80-column cards. Using this fact as a point of departure, the system was evolved to encompass four imperatives:

1. It must translate the punched code to the 6-bit Univac code, adding the appropriate check and sprocket pulses and detecting mispunchings as it converts.
2. It must distribute the 12-row 80-column data grouping within Univac's 720-digit block length, and insert the 2.4-inch space between blocks.
3. It must feed the cards through a sensing device in such a fashion as to tolerate off-punchings.
4. It must transport a tape and record on it.

The first problem is easily solved by a translating matrix which has 12 inputs from the photoelectric cell sensing array and 8 outputs to the channels of the recording head. This solution obviates the necessity of using any kind of memory in the converter, since the cards, feeding endwise, are sensed serially, and the material appears at the output in the order initially encoded on the cards.

The compromise between the 12-row 80-column grouping on the card and the 720-digit Univac block was effected by subdividing the block into 120-digit blockettes. The 80 digits of the card are encoded in the first 80 digit-positions of each blockette, and ignore symbols are read into the next 40 digit-positions. Effecting a 1 to 1 ratio between card and blockette presents an easy solution to the problem of inserting the space between blocks. This 2.4 inches of tape length is equivalent, at our recording speed, to 240 digit positions, or the data from two cards. Therefore a counter was designed into the system which feeds one card per cycle for six cycles (6 × 120 = 720), and then cycles twice with the card feed suppressed.

The card-feed and card-sensing design presented the weightiest problems because, in evolving them, it was essential to consider constantly the possibility of off-punched cards. These have always been a problem in sensing. It was desired to increase the tolerable limits of off-punching to an optimum.

Card Feed

The input bin of the card-to-tape converter stores 2,000 cards, which are fed at a cyclic rate of 470 per minute. Since two out of every eight are suppressed, the effective translation rate is 354 cards per minute.

The cards are fed endwise to a large openwork drum which carries them over a lineup of 12 photoelectric cells. The photoelectric cells read the punches, feeding their output to the translating matrix. The matrix output drives the head amplifiers, and so causes the head to record on the magnetic tape. Two cycling signals are produced at the same time: one for the read-6-suppress-2 cycle of the card feed, and the other a sprocket pulse to inspect the output of the photoelectric cells for every possible digit-position and establish the duty cycle of the recording head. At all times when cards are being fed through the sensor, the center-drive motor on the tape panel moves the tape across the recording head at a continuous speed of 10 inches per second.

The input hopper is inclined 15 degrees toward the picker knife. This angle was chosen to obtain the condition whereby cards would slide to the picker knife of their own weight, and yet not load the end of the hopper with the full weight of the 2,000 cards. To overcome any possible warp in the cards, a carriage was designed which uses a typewriter return spring to apply pressure through a plate to the top of the stack.

A latch arrangement, operated by a magnet, controls the feed mechanism. Pulsing of the magnet causes the cards to feed; no pulse is provided during the suppress-2 part of the feed cycle. The system is consequently fail-safe.

The picker knife strips a card from the bottom of the deck and pushes it into the inject roller system. The inject rollers carry the card 6.375 inches and introduce it to a drum which is 30 inches in circumference. The rollers turn at a high rate of speed, and a considerable amount of experimentation went into finding the proper material to withstand the combined effects of speed, tension, and heat.

Reading Drum

The drum is geared to the inject rollers at a ratio slightly less than one, so that the card hits the drum stop at a higher speed than that of the drum. The card buckles because of the difference in speed. The act of buckling causes the card to be forced against the forward card stop. Another set of friction drives keeps the card on the drum after it leaves the inject rollers.

When the card has traveled on the

---


Blumenthal, Lopez—Punched-Card to Magnetic-Tape Converter

Figure 1. Card-to-tape converter